DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
WATER DEPARTMENT, CITY OF PHILADELPHIA
AND THE
DELAWARE GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS
ATLAS HA-335 (SHEET 2 OF 2)

CONDITIONS IN 1966

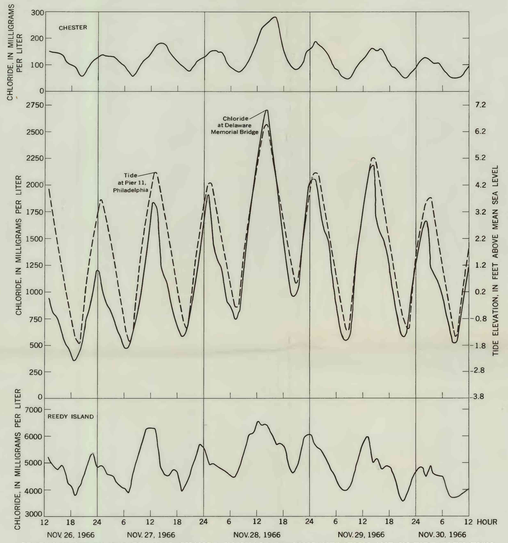
TIDE AND SALINITY

One of the major factors that controls salinity in the estuary is the tide (see Salinity). Two high tides and two low tides occur daily. As the tide level rises, salt water moves upstream, and as the tide ebbs, fresh river water moves downstream. Salt water continues to move upstream for some time after the tide reaches its maximum height. Reversal of current, or slack water, occurs an hour or two after high tide. Maximum salinity is at the time of slack water following low tide (see graphs right). There are two maxima in chloride concentrations each day which correspond to the two high tides, and there are two minima in chloride concentrations each day which correspond to the two low tides. The plot of tidal elevations is for Pier 11, and the plot of chloride concentrations, superimposed over the elevations, is for the Delaware Memorial Bridge, 31 miles downstream. The tides occur about 2 hours earlier at Delaware Memorial Bridge than at Pier 11. The salinity changes are in phase with the reversal of current and occur about 1 hour later than the tide elevation changes. Therefore, the salinity changes at Delaware Memorial Bridge are about 1 hour earlier than the tide elevation changes at Pier 11.

In the same figure are plotted, the chloride concentrations at Chester, at Reedy Island, and at the Delaware Memorial Bridge. The three plots of chloride concentrations have different scales on the ordinate axis, but at each of the three locations the chloride concentrations go through an equivalent cycle corresponding to the changes in tidal level.

The average salinity is affected by changes in river level, which responds to changes in sea level at the mouth of the estuary. A change in river level can be caused by a difference of barometric pressure between the two parts of the estuary or by prolonged on-shore winds. A wind from the south or outheast blows sea water into the bay and raises the level of water, favoring the upstream movement of salinity in the estuary. An offshore wind may blow water out of the bay and lower the water level, causing a downstream movement of fresh water. The elevation of one high tide may be greater than the immediately preceding or following one. The higher tide usually includes the higher salinity maximum.

Chloride profiles are drawn for the maximum daily salinity, since that is of the greatest concern to industries using the river water. At any location on the river the chloride concentration varies with the tide. Water with a particular chloride concentration moves upstream and downstream twice daily over a range of as much as 5-7 miles. The daily maximum, mean, and minimum chloride concentrations expected at League Island, Eddystone, and Marcus Hook for the average discharge at Trenton of the preceding month were tabulated on sheet 1. The table which includes these three locations, shows the daily variations in salinity due to the tides. The range of chlorides, expressed as percentage of the mean chloride concentration, is greater in the downstream direction.



GRAPHS SHOWING SEMIDIURNAL CHANGE IN CHLORIDE CONCENTRATION AND IN TIDE ELEVATION

Average values of daily maximum and minimum chloride concentration, as percent of daily mean

Location	Max	Mean	Min
Torresdale	116	100	94
Pier 11, Philadelphia	111	100	89
League Island	118	100	86
Eddystone	127	100	83
Chester	130	100	83
Marcus Hook	136	100	78
Delaware Memorial Bridge	156	100	64

SALINITY AND DISSOLVED OXYGEN – 1966

By the end of 1965 the basin had experienced 52 consecutive months of drought. Since October 1, 1961 the streamflow at Trenton was nearly 5 million million gallons less than the normal flow, a deficit equivalent to about 21 months of normal flow. This was the most prolonged and most severe drought on record in the Delaware River basin, exceeding the drought of 1929-32.

Most of the precipitation during January 1966 was in the form of snow, and the fresh-water discharge at Trenton was again below normal. Abnormally high and low tides caused an increase in salinity movement upstream and a corresponding fresh-water shift downstream. Dissolved-oxygen concentrations increased during the first 6 weeks of the year, especially from Pier 11 to Chester. Rains and warmer weather on February 13 melted the snow pack and produced a high runoff (28,000 cfs on February 14). Salinity was flushed seaward and dissolved-oxygen concentrations increased between Pier 11 and Chester. A decrease in dissolved-oxygen at Delaware Memorial Bridge occurred as the oxygen sag was pushed downstream by the increased river flow (see maps of February). Runoff was relatively high in March. At the end of the month the 50-mg/l line was a mile or two downstream from the Delaware Memorial Bridge (see map of March 27-29), and the dissolved-oxygen concentration exceeded 5 mg/l in nearly all of the estuary (see map of March 27-29).

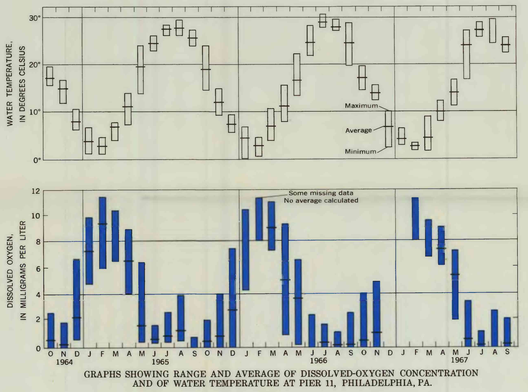
Fresh-water flow at Trenton decreased from 11,700 cfs on April 1 to less than 5,000 cfs during April 19-21 (see discharge hydrograph). Salt water moved upstream. On April 20 the 1,000-mg/l chloride line had reached Delaware Memorial Bridge, although salinity changes at Chester were not significant. By April 25 the daily minimum dissolved-oxygen concentrations were 1.1 mg/l at Pier 11 and 0.2 mg/l at Chester. In response to greater fresh-water flow at the end of April, salinity receded, and dissolved-oxygen concentrations increased in early May. On May 26 the 50-mg/l line was at the Pennsylvania – Delaware State line, the 250-mg/l line 2 miles downstream from Delaware Memorial Bridge, and the 1,000-mg/l line near the Chesapeake and Delaware Canal (see map of May 25-27). The dissolved-oxygen sag was still present and more severe than in April (see map of May 25-27). On May 26 several hundred dead fish were found downstream from Delaware Memorial Bridge and others near Pier 11 as a result of the deficiency in dissolved oxygen.

Water temperatures increased in March, April, May, June, and July an average of 5°C per month (see water temperature graph). The oxygen was depleted, and the reach of the river from Philadelphia to Marcus Hook had an oxygen concentration of 0-1 mg/l for most of that time (see maps of June 1-3 and July 1-3).

The average fresh-water discharge at Trenton was 2,554 cfs in July, 2,484 cfs in August, and 2,726 cfs in September. The average discharge for the 3 months was less than one quarter of the annual mean discharge (11,550 cfs for 1912-65). During each of these months salinity intruded farther upstream (see maps of August 9-11 and September 13-15). Rainfall on September 14-15 and 21-22 caused modest increases in streamflow on the following days with some recession of the salt fronts (see map of September 23-25). The dissolved-oxygen sag increased slightly from its July limits during August and September (see maps of August 9-11 and September 23-25). Increases in streamflow in October, especially on October 19-22, pushed the salt fronts farther downstream (see map of October 23-25). The location of the salt fronts changed little between October 25 and November 18, when the 50-mg/l, 250-mg/l, and 1,000-mg/l lines were at 102, 79, and 69 miles above the mouth of the bay. The dissolved-oxygen sag had almost disappeared by November 18 (see map of November 18-20). On November 28 a high tide moved these three salt lines 2, 6, and 9 miles farther upstream (see map of November 28); they returned to their previous locations when the tide returned to normal. Seasonal increased precipitation and increased streamflow in December reduced salinity and increased dissolved-oxygen concentrations.

The graphs at left show the range and average of dissolved-oxygen concentrations and the water temperatures for each month during 1965 to 1967. As monthly mean water temperature decreases as the monthly mean dissolved-oxygen concentration of the water increases. In 1965 and 1966 the mean water temperature decreased below 27°C first in September, and the mean dissolved-oxygen concentration began increasing in October. In the spring of 1965, 1966, and 1967 the mean water temperature rose to 4°C by March, and the mean dissolved-oxygen concentration began decreasing about the same time. The lowest water temperatures and highest dissolved-oxygen concentrations are in January, February, and March. The highest water temperatures are in July, August, and September, and the lowest dissolved-oxygen concentrations generally occur in the same 3 months.

The percent of time for which various dissolved-oxygen concentrations were equalled or exceeded in the 1965 and 1966 water years is given in the following table. The median values where dissolved oxygen was equalled or exceeded 50 percent of the time were 11.6 mg/l at Trenton, 7.0 mg/l at Torresdale, 1.3 mg/l at Pier 11, and 5.9 mg/l at Delaware Memorial Bridge. The dissolved-oxygen sag in the Philadelphia reach of the river shows partial recovery at Delaware Memorial Bridge. In one set of proposed "criteria for water quality" a lower limit of 3.5 mg/l is set for dissolved-oxygen concentration. In the 1965 and 1966 water years the dissolved-oxygen concentrations were less than 3.5 mg/l for 17 percent of the time at Bristol and at Delaware Memorial Bridge, but 59 percent of the time at Pier 11.



GRAPHS SHOWING RANGE AND AVERAGE OF DISSOLVED-OXYGEN CONCENTRATION AND OF WATER TEMPERATURE AT PIER 11, PHILADELPHIA, PA.

Dissolved-oxygen concentrations equalled or exceeded for indicated percent of time, 1965 and 1966 water years

Location	Percent of time								
	1	5	10	25	50	75	90	95	99
Trenton	15.2	14.6	14.0	13.1	11.6	9.6	7.8	7.1	6.2
Bristol	13.8	13.2	12.5	10.8	6.4	4.1	2.8	2.2	1.2
Torresdale	12.8	12.2	11.7	10.0	7.0	5.0	3.8	3.1	1.8
Pier 11	10.9	9.8	8.8	6.2	1.3	.5	.3	.2	.1
Chester	8.8	7.6	6.4	4.0	1.6	.5	.2	.1	.1
Delaware Memorial Br	10.6	9.2	8.4	7.3	5.9	4.4	2.6	1.7	.6

SUMMARY

During the last 2 years (1965-66) of an extensive drought salinity advanced farther upstream in the Delaware estuary than had been recorded previously. The farthest advance was in late summer and autumn when fresh-water flows into the estuary were lowest; salinity receded in late winter and early spring when snowmelt resulted in increased streamflow. The salinity at several locations in the estuary may be predicted from the discharge of fresh water at Trenton, if the discharge is steady. Fluctuations in discharge, or winds at the mouth of the estuary, often cause variations in the salinity. Salinity fluctuations occur daily with the rise and fall of the tides, and exceptionally high or low tides produce relatively high or low salinities. The daily range of salinities depends upon the range of tides but also varies with the location in the estuary. The farther seaward, the greater is the average range in salinity, expressed as percent of the daily mean.

As the tide rises, water moves upstream, and as the tide falls, water moves downstream. Except for downstream flushing by fresh water flowing into the estuary, the same water may oscillate upstream and downstream past any reference point along the bank. Pollutants introduced into the river at any location may remain there for several days until they are decomposed by oxidation. Thus, a dissolved-oxygen sag is more extensive and severe in that part of the estuary where most wastes are discharged. A large fresh-water flow shifts the sag farther downstream.

Dissolved-oxygen concentrations in the estuary are also seasonal. As early as May (1965-66) a considerable reach of the estuary had a dissolved-oxygen concentration of less than 1 mg/l, but by November the dissolved-oxygen concentration had recovered. This is in part a reflection of fresh-water flow which both dilutes the pollutants and brings in more oxygen to oxidize them. Perhaps, more significantly, the dissolved-oxygen deficit is related to the water temperature. In the summer river water is warm, the pollutants are oxidized more rapidly, and thus consume dissolved oxygen faster. In the autumn the water temperature decreases and oxygen is consumed less rapidly at the lower temperature. Not only is oxygen depleted less rapidly, but the cooler water is capable of dissolving greater concentrations of oxygen. Such an increase in dissolved-oxygen concentration is observed when the river water temperature falls below 27°C. In the winter oxidation reactions are slower in the cold water, and the dissolved oxygen is consumed slowly. When the river water warms with the coming of spring, the dissolved oxygen is consumed more rapidly. A decrease in the dissolved-oxygen concentration is observed when the river water temperature rises above 4°C.

REFERENCES

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Malcolm, Jess W., 1964, Delaware River Basin Commission fish studies: A progress report, presented at the annual Delaware River basin water resources conference in Buck Hill Falls, Pa.

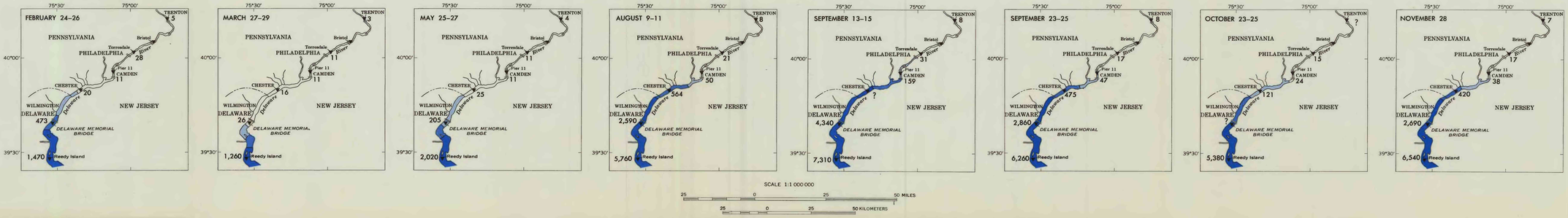
McCarthy, L. T., Jr., and Keighton, W. B., 1964, Quality of Delaware River water at Trenton, New Jersey: U.S. Geol. Survey Water-Supply Paper 1779-X, 51 p.

EXPLANATION

▼20
Quality sampling site
Number is chloride concentration, in milligrams per liter

Less than 50 | 50–250 | 250–1000 | >1000

Daily maximum chloride concentration, in milligrams per liter



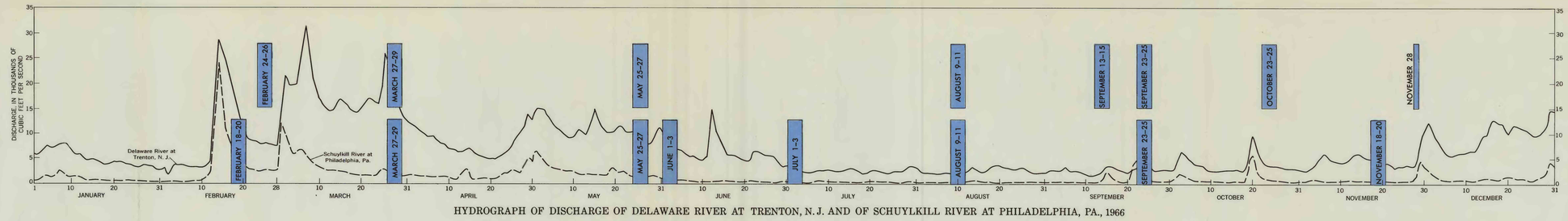
SCALE 1:1 000 000
25 0 25 50 MILES
25 0 25 50 KILOMETERS

MAPS SHOWING MAXIMUM CHLORIDE CONCENTRATION FOR SELECTED DATES, 1966

NOTES FOR DISCHARGE HYDROGRAPHS

The colored blocks at the top indicate the dates corresponding to each of the eight chloride concentration maps above.

The colored blocks at the bottom show the dates corresponding to each of the eight dissolved oxygen maps below.



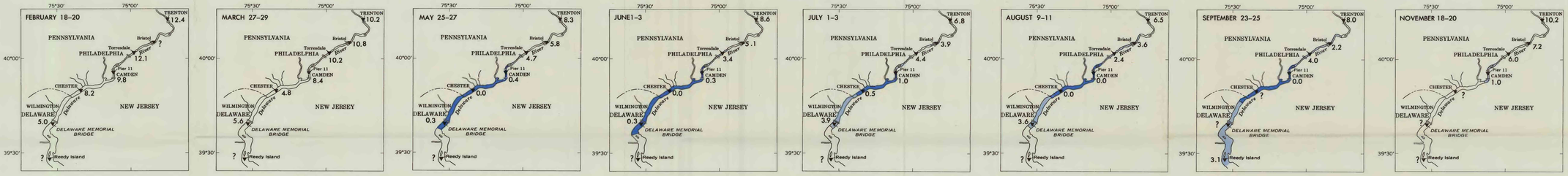
HYDROGRAPH OF DISCHARGE OF DELAWARE RIVER AT TRENTON, N.J. AND OF SCHUYLKILL RIVER AT PHILADELPHIA, PA., 1966

EXPLANATION

▼8.2
Quality sampling site
Number is dissolved oxygen concentration, in milligrams per liter

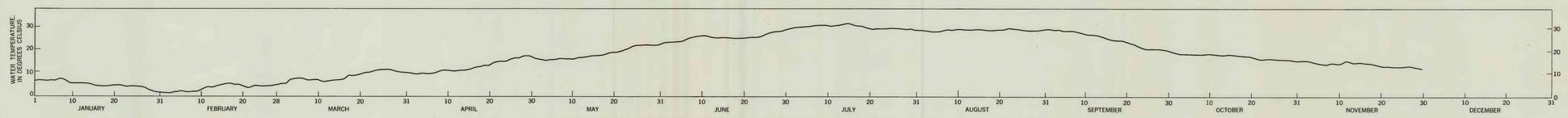
More than 4.0 | 1.0-4.0 | Less than 1.0

Daily minimum dissolved-oxygen concentration, in milligrams per liter



SCALE 1:1 000 000
25 0 25 50 MILES
25 0 25 50 KILOMETERS

MAPS SHOWING MINIMUM DISSOLVED-OXYGEN CONCENTRATION FOR SELECTED DATES, 1966



GRAPH OF DAILY AVERAGE RIVER WATER TEMPERATURE AT PIER 11, PHILADELPHIA, PA., 1966

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WATER QUALITY IN THE DELAWARE ESTUARY FOR TWO YEARS OF DROUGHT: 1965 AND 1966 FROM TRENTON, NEW JERSEY TO REEDY ISLAND, DELAWARE

By
Walter B. Keighton
1969